Internet of things communications for remote sensors in Antarctica using NVIS

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INTERNET OF THINGS COMMUNICATIONS FOR REMOTE SENSORS IN ANTARCTICA USING NVIS

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SUMMARY

In the last years, the concept of Internet of Things (IoT) is increasingly present in our lives. For that purpose, new IoT networks are being deployed to offer an extended coverage for low bit-rate and low-power communications. Currently, there are solutions based on either existing infrastructure of mobile telephony operators or independent of any telecom operator. In remote areas, the cost of those facilities becomes unfeasible, and the concept of Remote Internet of Things (RIoT) arises. In that case, High Frequency (HF) communications are very well suited to provide coverage to these areas. Using the Near Vertical Incidence Skywave (NVIS) technique, we can send the data from a sensor placed up to 250 kilometres away without the need of line-of-sight. The signal is transmitted vertically and reflected by the ionosphere, so a circular coverage area independent of the terrain obstacles is provided. In order to improve the autonomy of the system, we had to properly select the transmission frequency and design the antenna. Moreover, we also tested different modulations to find a trade-off between bit-rate and power consumption.

In this paper, we present a new technology solution for Remote Internet of Things based on NVIS communications. In particular, we describe the field trial installed and tested in the Spanish Antarctic Base Juan Carlos I during the 2018-2019 campaign. The results indicate that the system could be very useful for the Antarctic scientific community and extend the influence area of the Antarctic Bases.

1 INTRODUCTION

Antarctica is a continent dedicated to science according to the Antarctic treaty formed by twenty-nine Consultative Parties and twenty-four Non-Consultative Parties around the world [1]. Every year the investment from countries on science is growing in this remote area. The scientific community make use of different kind of sensors to analyse meteorological aspects, geophysical magnitudes, movement of glaciers, permafrost temperatures, among others. Some of these sensors are near to the base and the scientists can easily access to the sensor data. However, there are sensors that need to be located far from the base where the scientists are not

able to read the data frequently. Even if the locations are relatively close, the access may be difficult due to the weather conditions such as snow storms or brass, or the complicated terrain. Moreover, although most of the bases are open only during the Antarctic summer, they have a limited internet connection throughout the year. Thus, a system to communicate the sensors with the base is welcomed. Currently, the main solutions for IoT communications are Sigfox, LoraWan and NBIoT. Although the coverage of these networks is large (tens of kilometres), there is no global coverage in remote areas. In that case, satellite and HF communications are the only feasible solutions. Satellite solutions are usually too expensive and may not work under heavy weather conditions, such as snow and rain. In addition, the visibility of the satellite from polar regions is not always guaranteed.

On the other hand, the use of the HF communications is more affordable, and there are no problems of coverage and weather conditions. The HF band (3-30 MHz) is characterized by the ionospheric reflection. The reflection of the waves in the upper layer of the atmosphere is possible because of the ionization caused by the incidence of the ultraviolet radiation of the sun, the terrestrial magnetic field and the angle of incidence of the wave. [2] The HF connection can be established between two points of the planet using multiple-hop oblique reflection or can be established in a range of 250 kilometres using the NVIS technique.

During the last fifteen years, our research group has been working on HF applications. First, we focused on a multiple hop oblique communication along 12.700 km between the Spanish Antarctic Base Juan Carlos I at Livingston Island (Shetland South, Antarctica) and the Ebre Observatory at Roquetes (Tarragona, Spain). We modelled the ionospheric channel and tested a wide range of modulations and different types of oblique antennas optimized for large distance communications [3]–[8].

Currently, we are working on a low-power half-duplex NVIS system able to transmit and receive in real-time all sensor data from a radius of 250 kilometres away without the need of line-of-sight. This system can make data collection easier to the Antarctic scientific community.

2 SYSTEM DESCRIPTION

The proof of concept was deployed around the Spanish Antarctic Base Juan Carlos I, situated at Livingston Island, one of the Shetland South Islands, at the north of Antarctica continent as we can see at Figure 1.

The testing of the prototype was performed during the 2018-2019 campaign from January to March. A network of three NVIS nodes was implemented (see Figure 2). The main node was placed at the laboratory of the Spanish Antarctic Base, while two other locations were selected for the remote nodes. The location 1, Argentina Cove is only 1.34 Km away and is the nearest location to the base. For that reason, it is the most critical because the waves can travel either by the groundwave or by ionospheric reflection. This kind of multipath may cause a significant increase of the Bit Error Rate if it is not treated correctly. On the other hand, the location 2, Rocky Glacier is 5.7 kilometres far away from the base. In this case, the received signal in each node comes generally from one unique path, since there is not superficial wave. In some cases, there are two ionospheric paths, but they are not so critical as in the previous case.

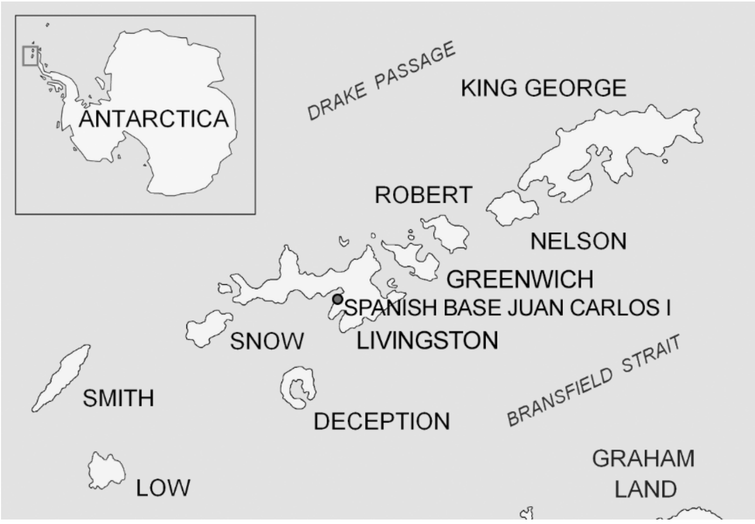

Figure 1. Shetland South Islands [9]

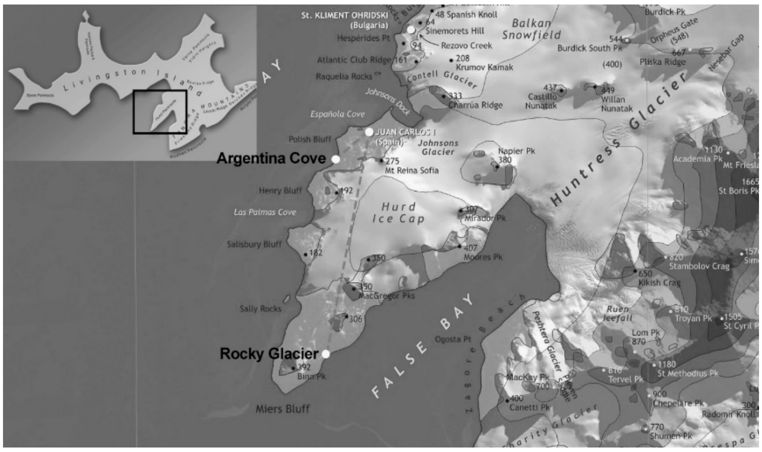

Figure 2. Location of the nodes [10]

The choice of the different locations has been done taking into account the logistic capabilities and the environmental impact. We also tried to minimize the propagation of the ground wave, selecting high and abrupt mountains between the base and the remote node location. In the case of Argentina Cove the presence of both ground and ionospheric waves was interesting for the study of its interaction. In the case of Rocky Glacier we succeed to supress the ground wave completely. We can see at Figure 3 and Figure 4 the elevation profile from the base Juan Carlos I to Argentina Cove and Rocky Glacier respectively.

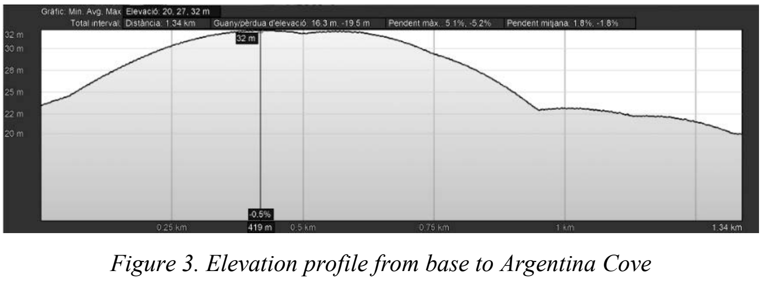

Figure 3. Elevation profile from base to Argentina Cove

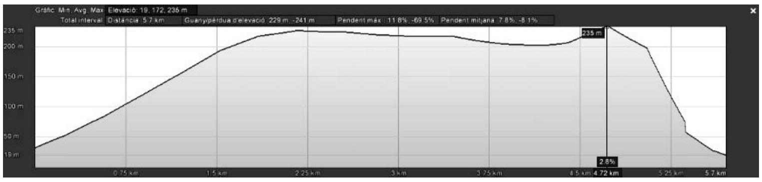

Figure 4. Elevation profile from base to Rocky Glacier

The hardware of the platform is composed of two principals parts: the transceiver node and the sensors. The sensors are connected with the node via Zigbee, while the transceiver collects the sensor data and processes it for transmitting as an HF signal by NVIS. The wave is sent upwards and is reflected by the F2 layer, so it can be received in a radius coverage of 250 kilometres without line of sight. The central node receives and stores the data from all sensors.

The main parts of the hardware prototype are shown in Figure 5.

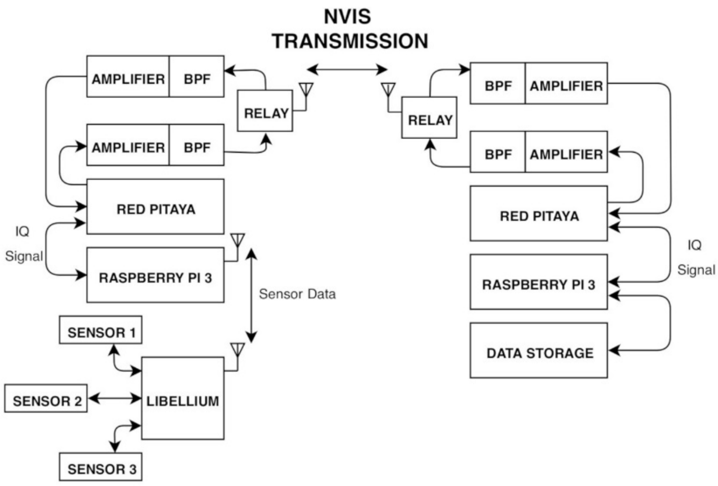

Figure 5. Schematic of the prototype [11]

The heart of the system is the Red Pitaya platform, composed by an ARM (Advanced RISC Machines) and FPGA (Field Programmable Gate Array), which implements the radiofrequency transmitter and the receiver. The Software Defined Radio (SDR) approach allows us to develop different functions into the same platform. We can perform channel soundings, modulation tests and a real-time communication system on the same hardware. The reader is referred to [12] for a detailed description. A Linux operative system mounted on the ARM is in charge of upsampling and downsampling the IQ data frame from 100 Ksps to 125 Msps or vice versa. A 14-bit ADC (Analogic to Digital Converter) and a 14-bit DAC (Digital to Analogic Converter) acquires and generates the HF signal. For detecting the start of frame, a 6^{th} order PN sequence is transmitted in the header. Red Pitaya is always correlating the signal input with the PN sequence to detect the peak of correlation. When a start of frame is detected, the Red Pitaya sends an IQ file with the baseband samples to the Raspberry Pi 3.

On the other hand, a Raspberry Pi 3 with a Linux operative system is in charge of mounting and demounting the frames. In transmission mode, the Raspberry Pi 3 modulates the data as an IQ data file and sends it to the Red Pitaya for the up-conversion. It also adds the 6^{th} order PN sequence as start of frame and a 600 Hz tone to correct the frequency Doppler at the beginning of the IQ file. In reception mode, the Red Pitaya sends an IQ data file to the Raspberry Pi 3 for

correcting the frequency Doppler and demodulating the data. In the case of the remote node, the Raspberry Pi 3 also receives the data from the Libelium sensors [13], via a serial gateway module that receives the data through a Zigbee protocol at 2.4 GHz. Then, the Raspberry Pi 3 collects the data, modulates it and prepares the frame for the transmission. In this prototype, we installed sensors of temperature, pressure, humidity and luminosity. The sensors have been configured for taking measurements every 5 minutes and the remote node for transmitting the data every 15 minutes.

Regarding the radiating system, an inverted V antenna was selected for its trade-off between simplicity and gain. For the installation of the inverted V, you only need a single mast. Moreover, most of the energy has to be radiated between 70º and 90º of elevation angle, ensuring the NVIS transmission [14]. After some simulations with the 4NEC2 software, the final dimensions of the antenna are shown in Figure 6 and Table 1. The height of the antenna has to be around 0.16λ and 0.22λ depending on the type of soil as we can see at [15]. A detailed description of the antenna design is found in [11]. At Figure 7 we can see the real system located at Rocky Glacier.

The selected frequency of transmission was the result of checking the last years' ionograms of Ebre Observatory [16] and Lowell Digisonde International [17]. At Figure 8 we can see an ionogram of Livingston, courtesy of Ebre Observatory. The frequency was set to 5 MHz.

Table 1. Optimization of the inverted-V antenna (Ideal: ideal ground plane (infinite conductivity), Rural: conductivity of 0.01 and 15 of dielectric constant (farmland and low hills), Permafrost: conductivity of 0.00005 and 3 of dielectric constant).

Soil type	Optimization algorithm	Gain (dBi)	SWR	Impedance (Ω)	Mast h. (m)	Min h. (m)	Yf (m)
Ideal	**Evolve**	6.8	1.96	25.6+3.2j	11.01	2.00	12.39
Rural	**Evolve**	3.8	1.05	47.7+0.4j	10.81	1.87	12.39
Permafrost	**Evolve**	1.3	1.27	63.3-1.0j	13.08	2.00	11.51

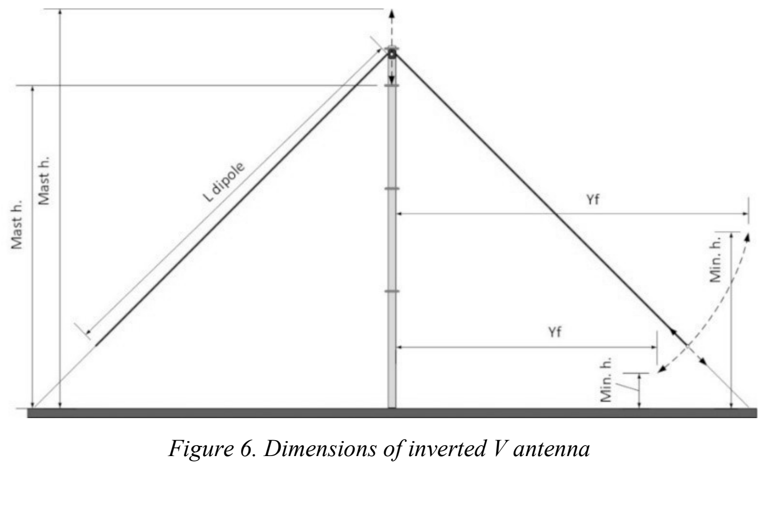

Figure 6. Dimensions of inverted V antenna

Figure 7. System located at Rocky Glacier

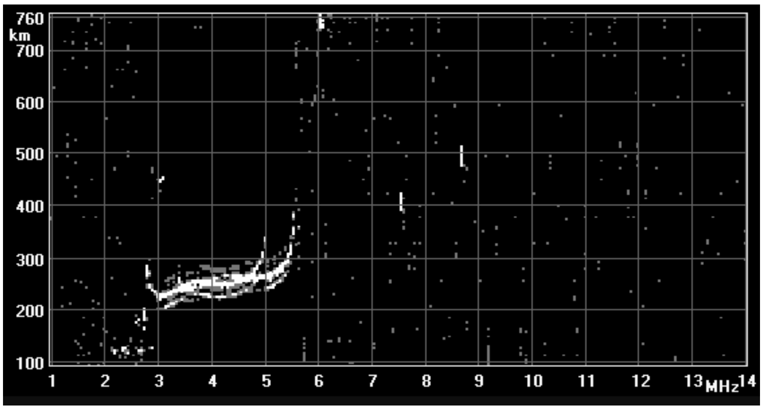

Figure 8. Livingston Ionogram

A half duplex protocol was implemented to ensure frames free of errors. All the received frames by the base node include a FCS (Frame Check Sequence) which is verified. If the checksum is correct the base node sends an ACK to the remote node. If the checksum is incorrect the base node requests a retransmission of the data. If the remote node does not receive an answer, it will resend the data up to three times. After that, the remote node assumes bad propagation and will resend the data in the next configures transmission interval.

We have also tested the best modulation that suits better the NVIS channel. The study was focused on QAM, FSK, PSK modulations from 2 to 32 symbol order, with bandwidths between 2.3 KHz and 20 KHz, and power transmissions between 0.75 W and 24 W. The best choice was a 4QAM modulation with a power transmission of 24 W. The bandwidth was 2.3 KHz in all cases to be consistent with the HF standards [18].

Regarding the power consumption of the system, the remote nodes were powered by lead-acid batteries, while the central node was mains-operated. At this stage of the project, we did not consider any type of alternative source of energy for the remote nodes. The system has been working for 15 days with a power consumption of 31.2 W in reception mode. On the other hand, when the transmitter is running the consumption raises to 55.2 W during less than 3 seconds. In both cases, the values are acceptable, since no energy saving measures have been applied. The lead-acid batteries allowed the system to working for 7 days continuously.

3 RESULTS

The results have been obtained from the tests performed during the 15 days that the system was operative. The Cumulative Distribution Function (CDF) of the Bit Error Rate (BER) is the probability of having a BER (Bit Error Rate) lower than a given value. Figure 9 shows the CDF of the transmissions done with a 4QAM modulation with a bandwidth of 2.3 Khz and an output power of 24 W. We have to consider that all these results are calculated without any ECC (Error Correction Code) used.

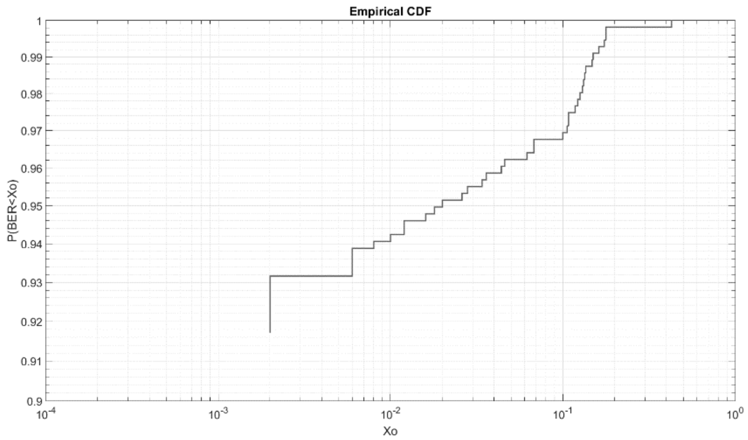

Figure 9. CDF of 4QAM

Another interesting topic is the percentage of retransmitted frames, when a bit error occurs. We should be aware that all the transmissions are done with a single frequency during the whole day. Hence, the frequency of 5 MHz may not be reflected at night in the same way as is reflected in daytime. In Figure 10 we can see the probability of receive the data without any error for every retransmission in case of error. The calculated probabilities are based on a Bernoulli distribution. In the worst case scenario, the probability of a retransmission is about 6.83% and the 93.17% of the packets are correctly received. In the case of three retransmissions (including the first transmission), the probability of fail is about 0.0022%.

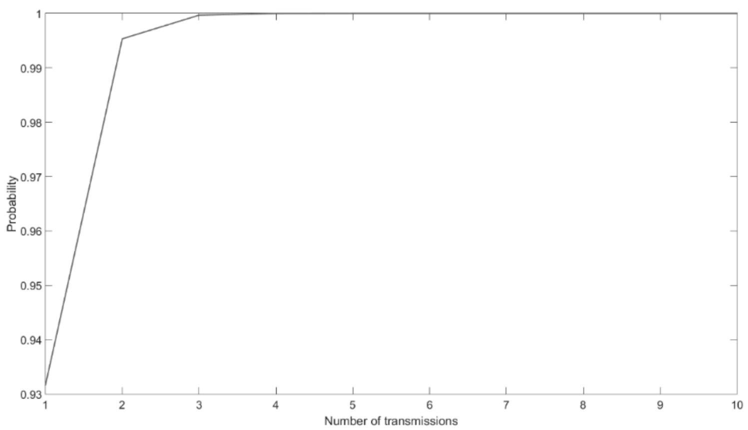

Figure 10. Retransmission probability of 4QAM

In Figure 11, we can see the evolution of the EbNo throughout the day for a transmission power of 24 W. The EbNo is close to 5 dB from 14 UTC to 22 UTC (Livingston Island time is CET-4 hours) which is enough for simple modulations such as FSK and BPSK. The night hours

between 22 UTC to 13 UTC are not shown, because the selected frequency did not exhibit good propagation during the night.

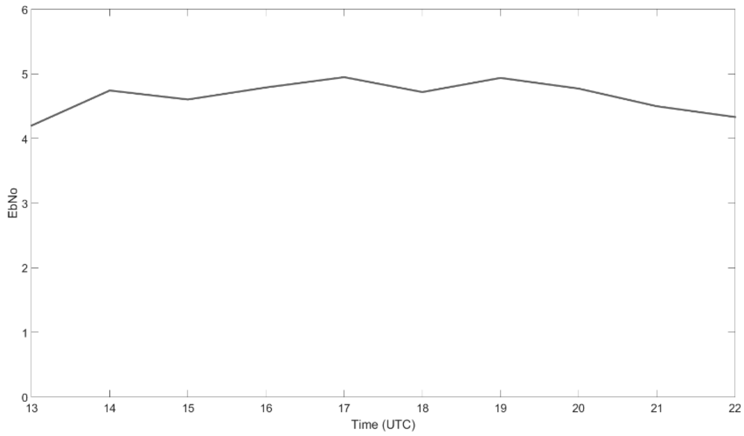

Figure 11. Mean EbNo received during the day

4 CONCLUSIONS

In this paper, we demonstrate the feasibility of the NVIS communications for sensors located in remote areas like the Antarctica. The SDR platform is suited for ionospheric soundings, modulation testing and the implementation of the real time communication system.

Several studies have been made to find out the best modulation, bandwidth and power transmission of the system. The developed system modulates the sensor data in a 4QAM with a bandwidth of 2.3 KHz and power transmission of 24 W. In those conditions, we can transmit at a maximum bitrate of 4.6 Kbps. We also implemented a protocol of error detection and retransmission. The probability of a retransmission is about 6.83%, and, in case of another bit error, the system will retransmit again when possible. These results were obtained without any Error Correction Code, so are a lower bound in performance. The consumption of the developed system in receiving mode is about 31.2 W and during the transmission mode is about 55.2 W. The remote system powered by lead-acid batteries has an autonomy of 7 days approximately. If we installed some kind of renewable source of energy, the system would be running for a long period of time.

In the future, the developed system could reach coverage areas larger than 250 km by using NVIS with multiple hops. In case of a node situated more than 250 km from the base node, this could establish a communication with the base node via an intermediate node located in the coverage area of the base node. This intermediate node will behave as a repeater from another node to the base node, establishing a communication by two NVIS hops.

Finally, we can conclude that this technology might be really useful to enlarge the study areas and the data availability of the Antarctic bases. The researchers will have access to sensors placed very distant from the bases and will save valuable time in collecting the data.

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